



(11) **EP 2 901 531 B1**

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention
of the grant of the patent:
11.07.2018 Bulletin 2018/28

(51) Int Cl.:
H01S 3/06 ^(2006.01) **H01S 3/08** ^(2006.01)
H01S 3/113 ^(2006.01) **H01S 3/0941** ^(2006.01)
H01S 3/16 ^(2006.01)

(21) Application number: **13842722.4**

(86) International application number:
PCT/US2013/052234

(22) Date of filing: **26.07.2013**

(87) International publication number:
WO 2014/051847 (03.04.2014 Gazette 2014/14)

(54) **MICROCHIP LASER WITH SINGLE SOLID ETALON**

MIKROCHIPLASER MIT EINEM EINZELNEN FESTKÖRPER-ETALON

LASER À MICRO-PUCES AYANT UN ÉTALON SOLIDE UNIQUE

(84) Designated Contracting States:
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
PL PT RO RS SE SI SK SM TR**

(30) Priority: **26.09.2012 US 201213627633**

(43) Date of publication of application:
05.08.2015 Bulletin 2015/32

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• **DONG J ET AL: "Composite Yb:YAG/Cr<4+>:YAG
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DOI: 10.1364/OE.15.014516**

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Description

TECHNICAL FIELD

[0001] This disclosure is generally directed to laser systems. More specifically, this disclosure is directed to a microchip laser with a single solid etalon and interfacial coating.

BACKGROUND

[0002] Laser devices generate narrow beams of light using optical amplification. Emission from lasers can be characterized as either single-longitudinal-mode or multi-longitudinal-mode emission. A key component of a laser is an optical cavity, which constrains a significant portion of the laser light to make multiple passes through a gain (amplifying) component. Laser cavities have resonant frequency modes separated by $c/2L$, where c is the speed of light in vacuum and L is the optical path length of the laser cavity. These frequency modes are also referred to as longitudinal modes of the laser cavity. Single-longitudinal-mode emission generally refers to light generated by a laser when only one of these frequency modes is present. In contrast, multi-mode emission generally refers to light generated by a laser when more than one frequency mode is present at the same time. Single-mode emission is often preferred over multi-mode emission for many reasons. One important reason is that multi-mode emission creates high intensity modulation spikes (mode-beating) which can be as much as N times higher than the peak intensity of single-longitudinal-mode emission, where N is the number of longitudinal modes simultaneously present. In the case of Q-switched or short-pulse lasers, the higher peak intensity associated with mode-beating can enhance parasitic nonlinear effects such as self-focusing or stimulated Raman scattering, as the laser light is transmitted through otherwise transparent optical media. In this case, it may be acceptable that the pulses consist of different longitudinal modes, so long as only one of these longitudinal modes is present within each pulse. In some remote sensing applications, single-longitudinal-mode emission is desired to efficiently couple into a narrow absorption line or transmit through a narrow optical bandpass filter. Also, mode beating is a source of noise. An etalon, or Fabry-Perot etalon, is a device often used in laser design as a wavelength or frequency mode selecting component. An etalon typically includes two flat, parallel optical surfaces that are separated by a gap. The gap can be filled with air (as in an "air-gap etalon") or include a solid material (as in a "solid etalon").

[0003] US 7,649,920 B2 discloses a monolithic passively Q switched microlaser including an optically transparent heat conductive element bonded to a gain medium, which is in turn bonded to a saturable absorber, which may also be bonded to a second optically transparent heat conductive element. Only the gain medium

and saturable absorber are disposed within the laser resonator.

[0004] US 5,825,465 A discloses an autodyne laser velocimeter comprising: a microlaser capable of emitting respectively a first and second beam, pumping means capable of supplying a pumping beam light to the microlaser, optical means capable of directing the first beam at a target and of sending the light re-emitted by the target to the microlaser, photoelectric detection means of receiving the second beam and emitting a detection signal corresponding to a modulation in the intensity of the second beam, and means of processing the detection signal to determine a characteristic magnitude of a displacement velocity of the target.

[0005] US 2003/039274 A1 discloses an apparatus and method for an efficient, passively Q-switched microlaser producing high peak power pulses of light of extremely short duration. This microlaser utilizes $\text{Yb}^{3+}:\text{YAG}$ as the gain medium instead of conventionally used $\text{Nd}^{3+}:\text{YAG}$ or $\text{Nd}^{3+}:\text{YVO}_4$ gain media. The utilization of $\text{Yb}^{3+}:\text{YAG}$ allows superior performance of the high peak-power microlaser in many aspects with respect to conventionally used $\text{Nd}^{3+}:\text{YAG}$ as the gain media. The efficiency of the pump of the microlaser (the so called optical-to-optical efficiency) can be higher by factor of two to four, with respect to $\text{Nd}:\text{YAG}$, provided all other output parameters such as pulsewidth, output peak power and spatial quality of the beam are equal. The improved efficiency allows reducing the cost and size of the whole microlaser system substantially. In addition to lowering the cost of the microlaser system by a factor of two to three, the temperature stability of the proposed microchip laser improved by a factor of 5, due to the wider absorption bandwidth of the $\text{Yb}^{3+}:\text{YAG}$ to those of $\text{Nd}^{3+}:\text{YAG}$ or $\text{Nd}^{3+}:\text{YVO}_4$.

[0006] DONG J ET AL. "Composite $\text{Yb}:\text{YAG}/\text{Cr}^{4+}:\text{YAG}$ ceramics picosecond microchip lasers", OPTICS EXPRESS, vol. 15, no. 22, 29 October 2007, pages 14516-14523, discloses laser-diode pumped picosecond self-Q-switched all-ceramic composite $\text{Yb}:\text{YAG}/\text{Cr}^{4+}:\text{YAG}$ microchip lasers which oscillate at stable single- and multiple- longitudinal-modes due to the combined etalon effects of the $\text{Yb}:\text{YAG}$ and $\text{Cr}^{4+}:\text{YAG}$ parts of its binary structure.

[0007] US 5 187 714 A discloses a laser-diode-pumped solid-state laser including a solid-state laser rod pumped by a pumping laser beam emitted from a semiconductor laser. The laser beam produced by the solid-state laser rod is oscillated by a resonator, and the wavelength of the oscillated laser beam is converted into another wavelength by an optical wavelength converter. The resonator is jointly provided by the solid-state laser rod and the optical wavelength converter. Alternatively, the solid-state laser rod may comprise a self-frequency-doubling crystal for producing a laser beam, oscillating the laser beam, and converting the wavelength of the oscillated laser beam into another wavelength.

[0008] US 5 796 766 A discloses a longitudinally-

cooled laser element assembly comprising an optically transparent heat sink (OTH) coupled to a laser element and a heat sink. An etalon structure including a first flat surface and a second, substantially parallel flat surface is formed in the laser element and/or the OTH. In some embodiments, a balanced etalon is provided by forming a reflector on the second flat surface of the etalon that has a reflectivity approximately equal to the Fresnel loss at the interface between the OTH and the laser element. In some embodiments, the laser element assembly includes a second OTH coupled to the laser element at a second interface, thereby defining a second Fresnel loss. Preferably, the second OTH has an index of refraction substantially equal to the index of refraction of the first OTH, so that the first and second Fresnel losses are approximately equal and a balanced etalon is formed. In some embodiments, the laser element comprises a solid-state gain medium. In other embodiments, the laser element comprises a nonlinear frequency conversion crystal. An intra cavity frequency-converted laser is described in which OTHs are used to cool both the gain medium and the nonlinear material.

SUMMARY

[0009] This disclosure provides a microchip laser with a single solid etalon and interfacial coating. The object of the invention is fulfilled by a device and a method as defined in the independent claims 1,7. Preferred embodiments are defined in the dependent claims.

[0010] In a first aspect, this disclosure provides a microchip laser comprising: a microchip laser base comprising a gain region and a passive Q-switch region; a solid etalon coupled to the microchip laser base; and an interfacial coating disposed between the microchip laser base and the solid etalon; wherein the microchip laser base and the solid etalon are comprised of a same host material; wherein the microchip laser base, the solid etalon, and the interfacial coating are bonded together without an adhesive; wherein the microchip laser base and the solid etalon form a laser cavity, thicknesses of the microchip laser base and the solid etalon being selected such that an emitted longitudinal mode of the laser cavity is at or near a peak reflectance of the solid etalon; and wherein either: an emitting outer surface of the solid etalon is an uncoated outer surface, and the interfacial coating has a reflectance that matches a Fresnel reflectance of the emitting outer surface of the solid etalon; or the emitting outer surface of the solid etalon has a surface coating, and the reflectance of the interfacial coating matches a reflectance of the emitting outer surface of the solid etalon.

[0011] In a second aspect, this disclosure provides a laser system comprising: a pump diode configured to produce light at a first wavelength; relay optics configured to receive the light from the pump diode; and a microchip laser according to the first aspect configured to receive the light from the relay optics.

[0012] In a third aspect, this disclosure provides a method of producing a laser output, the method comprising: producing a light at a first wavelength; receiving, at a microchip laser, the light at the first wavelength; and generating, at the microchip laser, the laser output, the microchip laser comprising: a microchip laser base comprising a gain region and a passive Q-switch region; a solid etalon coupled to the microchip laser base; and an interfacial coating disposed between the microchip laser base and the solid etalon; wherein the microchip laser base and the solid etalon are comprised of a same host material; wherein the microchip laser base, the solid etalon and the interfacial coating are bonded together without an adhesive; wherein the microchip laser base and the solid etalon form a laser cavity, thicknesses of the microchip laser base and the solid etalon being selected such that an emitted longitudinal mode of the laser cavity is at or near a peak reflectance of the solid etalon; and wherein either: an emitting outer surface of the solid etalon is an uncoated outer surface, and the interfacial coating has a reflectance that matches a Fresnel reflectance of the emitting outer surface of the solid etalon; or the emitting outer surface of the solid etalon has a surface coating, and the reflectance of the interfacial coating matches a reflectance of the emitting outer surface of the solid etalon.

[0013] Other technical features may be readily apparent to one skilled in the art from the following figures, descriptions, and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] For a more complete understanding of this disclosure and its features, reference is now made to the following description, taken in conjunction with the accompanying drawings, in which:

FIGURE 1 illustrates a laser system, according to an embodiment of the disclosure;

FIGURE 2 illustrates a single-longitudinal-mode microchip laser, according to an embodiment of this disclosure;

FIGURES 3A and 3B depict etalon and cavity mode graphs of the microchip laser of FIGURE 2, according to an embodiment of this disclosure;

FIGURES 4A through 4F depict graphs illustrating temperature sensitivity of the microchip laser of FIGURE 2, according to an embodiment of this disclosure;

FIGURE 5 illustrates a three-mode solid-etalon microchip laser, according to an embodiment of this disclosure; and

FIGURES 6A and 6B illustrate etalon and cavity mode graphs of the microchip laser of FIGURE 5, according to an embodiment of this disclosure.

DETAILED DESCRIPTION

[0015] FIGURES 1 through 6B, described below, and the various embodiments used to describe the principles of the present disclosure in this patent document are by way of illustration only and should not be construed in any way to limit the scope of the disclosure.

[0016] This disclosure provides a novel, robust means for obtaining a single frequency output with a microchip laser. The new laser device is not sensitive to adverse environmental conditions such as temperature changes and mechanical vibration and shock. It is also, by its nature, relatively insensitive to changes in diode pump power. The monolithic nature of its architecture allows for significantly less complex mounting hardware. This device is ideally suited for space and airborne active sensor applications.

[0017] Microchip lasers are well known in the art. In one example, a monolithic microchip laser includes an air-gap etalon attached to the body of the microchip. In most cases, however, the coefficient of thermal expansion (CTE) and temperature coefficient of refractive index (dn/dT) of the air-gap etalon are not matched to the body of the microchip. Thus, the etalon and microchip body become detuned with respect to each other as the result of temperature and pump diode current changes.

[0018] In another example, a microchip laser includes a volume Bragg grating (VBG). Typically, however, such a laser requires a two-piece or multi-piece (not monolithic) design where the components must be kept rigidly in alignment with one another. The multi-piece design is inherently more complicated than a monolithic design. Furthermore, the VBG mirrors are composed of materials that are dissimilar to that of the remainder of the microchip. Thus, the CTE and dn/dT values of the VBG are not matched to the body material of the microchip. Thus, a microchip laser with VBG may also be sensitive to changes in ambient temperature and pump diode current.

[0019] In a third example, ultra-thin microchip lasers featuring a monolithic design are known. However, to function as a single-frequency laser, the microchip laser must be thin so the longitudinal mode separation ($c/2L$) is large enough that only one mode lies within the emission line width of the gain material. For example, in the case of Ytterbium-doped YAG (yttrium aluminum garnet) (Yb:YAG), the microchip laser should not be thicker than approximately 220 microns. A thin microchip will have a correspondingly small transverse mode volume, and therefore the pulse energy will be significantly lower than some laser applications require.

[0020] To address these deficiencies in the art, embodiments of this disclosure provide a monolithic microchip laser with an attached solid etalon that acts to limit the number of longitudinal (frequency) modes. The monolithic microchip structure and attached solid etalon are constructed using the same host material and without the use of adhesives. An imbedded (interfacial) coating

is used in conjunction with an outer surface of the etalon to form the solid etalon. In accordance with certain embodiments, the outer etalon surface is uncoated. The outer etalon surface and the imbedded coating form a resonant-reflector outcoupler of the microchip. The attached solid etalon provides additional longitudinal mode discrimination and enables single-longitudinal-mode operation with a microchip thickness greater than that allowed for a monolithic microchip without an etalon.

[0021] FIGURE 1 illustrates a laser system 100, according to an embodiment of this disclosure. Although certain details will be provided with reference to the components of the laser system 100 of FIGURE 1, it should be understood that other embodiments may include more, fewer, or different components. The laser system 100 of FIGURE 1 includes a driver 102, a pump diode 104, relay optics 120, and a microchip laser crystal 130. As described in more detail below, the laser system 100 in this embodiment is configured to generate a laser output 140, such as a single-longitudinal-mode output.

[0022] The driver 102 in the embodiment of FIGURE 1 is configured to drive the pump diode 104, which in this embodiment produces energy, light, or electromagnetic radiation ("energy, light, or electromagnetic radiation" hereinafter referred to as "light"). In particular configurations, the driver 102 may produce either a continuous light wave or a pulsed light wave from the pump diode 104. Additionally, in particular configurations, the driver 102 may modulate the pump diode 104, for example, in producing the pulsed light wave.

[0023] The pump diode 104 is shown coupled via fiber to the relay optics 120. The relay optics 120 in particular configurations may transfer the light from the pump diode to the microchip laser crystal 130. One of ordinary skill in the art will recognize the details of the relay optics 120; accordingly, the details will not be explained. As recognized by one of ordinary skill in the art, relay optics 120 may include, among other components, lenses 122 and 124 to focus the light being transmitted therethrough.

[0024] The microchip laser crystal 130 in this embodiment includes a microchip laser base 132 and a solid etalon 136. The microchip laser base 132 absorbs the pump light and emits light at the laser system's output wavelength, as will be recognized by one of ordinary skill in the art. For example, the microchip laser base 132 may emit light at a wavelength of 1030 nm. The solid etalon 136 is attached to the microchip laser base 132 and is comprised of the same host material as the microchip laser base 132. Embodiments of the microchip laser crystal 130 in accordance with this disclosure will be described in greater detail below.

[0025] FIGURE 2 illustrates a single-longitudinal-mode microchip laser, according to an embodiment of this disclosure. Although certain details will be provided with reference to the components of the microchip laser 200 of FIGURE 2, it should be understood that other embodiments may include more, fewer, or different components. The microchip laser 200 could be used as the mi-

crochip laser crystal 130 in the laser system 100 of FIGURE 1. However, the microchip laser 200 could also be used in any other suitable device or system.

[0026] The microchip laser 200 includes a microchip laser base 210, a solid etalon 220, a reflective interfacial optical coating 230 and a dichroic coating 240. The microchip laser base 210 includes a gain region 212 and a passive Q-switch region 214 that are diffusion-bonded to each other. In an embodiment, each base region 212, 214 is formed of a crystalline YAG host. However, it will be understood that other materials, such as phosphate glass, may be used in the base regions 212, 214. In an embodiment, the base regions 212, 214 are lightly doped with laser-active ions (e.g. Er³⁺, Yb³⁺, or Nd³⁺) or saturable-absorber ions (e.g. Cr⁴⁺). For example, the gain region 212 may be doped with ytterbium (Yb) and the passive Q-switch region 214 may be doped with chromium (Cr). Also, the gain region 212 may be co-doped with both a laser-active ion and a sensitizer ion, e.g., Er and Yb. In such an embodiment, the sensitizer ion absorbs the pump light and transfers its energy to the laser-active ion. In another embodiment, the base 210 may be composed of a single region that is co-doped with both a laser-active ion and a saturable-absorber ion, e.g., Yb and Cr. In one embodiment, the microchip laser base 210 is approximately 0.8mm thick, although other thicknesses are possible, depending on the desired wavelength, pulse energy, and other properties.

[0027] The solid etalon 220 is composed of the same host material (e.g., crystalline YAG or glass) as the microchip laser base regions 212, 214. However, in an embodiment, the solid etalon 220 is not doped with laser-active or saturable-absorber ions. Because the doping concentrations of the base regions 212, 214 are relatively low, the thermal properties (e.g., CTE and dn/dT) of the etalon 220 and the base regions 212, 214 are closely matched. This characteristic helps to ensure that the microchip laser 200 is very insensitive to ambient temperature changes. The solid etalon 220 includes an uncoated outer surface 222. However, in some embodiments, it is possible to coat the outer surface 222. In one embodiment, the solid etalon 220 is approximately 220μm thick, although other thicknesses are possible, depending on desired wavelength, pulse energy, and other properties.

[0028] The interfacial coating 230 is applied at the interface between the solid etalon 220 and the microchip laser base 210. The reflectance of the interfacial coating 230 at the laser wavelength is selected to match the Fresnel reflectance of the uncoated outer etalon surface 222. In an embodiment, the reflectance of the interfacial coating 230 is approximately 8.5%. In embodiments where the outer surface 222 is coated, the reflectance of the outer surface 222 may be substantially matched to that of the interfacial coating 230. Together, the outer surface 222 and the interfacial coating 230 form a resonant-reflector outcoupler of the microchip laser 200.

[0029] The dichroic coating 240 is formed on a surface

of the microchip laser base 210 opposite from the interfacial coating 230. The dichroic coating 240 functions as an interference filter or color filter that selectively passes light in a small range of wavelengths while reflecting other wavelengths, as known in the art. In an embodiment, the dichroic coating 240 exhibits approximately 100% transmittance of light at a wavelength of 940nm, and approximately 100% reflectance of light at a wavelength of 1030nm.

[0030] The thicknesses of the solid etalon 220 and the microchip laser base 210 are selected so that a longitudinal mode of the net microchip laser cavity (formed by the base 210 and etalon 220) is at or near the peak reflectance of the etalon (resonant reflector). In an embodiment, the overall thickness of the microchip laser 200 is approximately 1.02mm. Thus, in operation, the spectrum of the etalon 220 does not go out of alignment with the cavity mode spectrum, as described in greater detail below. This is a novel approach to making a single-frequency microchip oscillator that reproduces the laser frequency on a pulse-to-pulse basis and allows broad temperature tolerance. The layers of the microchip laser 200 (the microchip laser base 210, solid etalon 220, reflective interfacial optical coating 230, and dichroic coating 240) are bonded together without adhesives. The monolithic nature of the microchip laser 200 allows for significantly less complex mounting hardware and makes the microchip laser much less sensitive to mechanical vibration and shock.

[0031] Although FIGURE 2 illustrates one example of the microchip laser 200, various changes may be made to FIGURE 2. For example, as shown in FIGURE 2, the solid etalon 220 is undoped. However, it is possible to dope the solid etalon 220 with an inert ion. In addition, although the base regions 212, 214 are doped with Yb and Cr respectively, the base regions may be doped with other ions or be formed of other materials.

[0032] FIGURES 3A and 3B depict etalon and cavity mode graphs of the microchip laser 200, according to an embodiment of this disclosure. Each of the graphs in FIGURES 3A and 3B includes an etalon plot line 305 and a cavity mode plot line 310. The etalon plot line 305 shows the change in the reflectivity of the etalon over different wavelengths. Similarly, the cavity mode plot line 310 depicts the cavity modes of the overall microchip cavity over different wavelengths. The plot lines in FIGURE 3B represent the same information as the plot lines in FIGURE 3A, however the scale of the X-axis in FIGURE 3B is compressed and more than one cycle of each curve is shown. As shown in FIGURE 3B, the period, or free-spectral-range, of the etalon plot line 305 is approximately 1.3nm. The free-spectral-range (FSR) is given by $\lambda^2/(2nL)$, where λ is the wavelength (in vacuum), n is the refractive index of the etalon, and L is the thickness of the etalon. In an embodiment, a FSR of 1.3 nm is sufficient to prevent lasing in the adjacent etalon orders for a microchip with Ytterbium-doped YAG as the gain medium. For microchip designs using other gain materials,

the etalon thickness may be adjusted so that the adjacent spectral peaks of the etalon reflectance are far enough away from the emission line peak to prevent lasing there.

[0033] FIGURES 4A through 4F depict graphs illustrating temperature sensitivity of the microchip laser 200, according to an embodiment of this disclosure. Like the graphs in FIGURES 3A and 3B, each of the graphs in FIGURES 4A through 4F includes an etalon plot line 405 and a cavity mode plot line 410. The graphs in FIGURES 4A through 4F depict the microchip laser 200 operating at 25°C, 30°C, 35°C, 40°C, 45°C, and 50°C, respectively. Because the solid etalon 220 and the microchip laser base 210 are composed of the same material, the cavity modes and etalon spectral peak track each other over different temperatures. The temperature range is limited only by the gain line width of the laser active section.

[0034] FIGURE 5 illustrates a three-mode solid-etalon microchip laser, according to an embodiment of this disclosure. Although certain details will be provided with reference to the components of the microchip laser 500 of FIGURE 5, it should be understood that other embodiments may include more, fewer, or different components. The microchip laser 500 could be used as the microchip laser crystal 130 in the laser system 100 of FIGURE 1. However, the microchip laser 500 could also be used in any other suitable device or system.

[0035] The microchip laser 500 is, in many respects, the same as or similar to the microchip laser 200 depicted in FIGURE 2. However, the thickness of the microchip laser 500 is greater than that of the microchip laser 200 in order to provide for higher pulse energy. In addition, the microchip laser 500 lases on one longitudinal mode per pulse, but does not lase on the same mode in every pulse.

[0036] Similar to the microchip laser 200, the microchip laser 500 includes a microchip laser base 510, a solid etalon 520, a reflective interfacial optical coating 530 and a dichroic coating 540. The microchip laser base 510 includes a gain region 512 and a passive Q-switch region 514 that are formed of crystalline YAG or another suitable material. In an embodiment, the gain region 512 is YAG doped with Yb³⁺ at a concentration of approximately 15%. The passive Q-switch region 514 is YAG doped with chromium Cr⁴⁺. The unbleached transmittance of the passive Q-switch region 514 at a wavelength of 1030nm is approximately 90%.

[0037] The solid etalon 520 is composed of the same host material as the microchip laser base regions 512, 514, but is not doped with laser-active or saturable-absorber ions. The thermal properties (e.g., CTE and dn/dT) of the etalon 520 and the base regions 512, 514 are closely matched, which helps to ensure that the microchip laser 500 is very insensitive to ambient temperature changes. The solid etalon 520 typically includes an outer surface 522 that is typically uncoated, but may be coated in some embodiments. In one embodiment, the solid etalon 520 is approximately 220μm thick, although other thicknesses are possible, depending on desired wavelength, pulse

energy, and other properties.

[0038] The interfacial coating 530 is applied at the interface between the solid etalon 520 and the microchip laser base 510. The reflectance of the interfacial coating 530 at the laser wavelength is selected to match the Fresnel reflectance of the uncoated outer etalon surface 522. In an embodiment, the reflectance of the interfacial coating 530 is approximately 8.5%. In embodiments where the outer surface 522 is coated, the reflectance of the outer surface 522 may be substantially matched to that of the interfacial coating 530. Together, the outer surface 522 and the interfacial coating 530 form a resonant-reflector outcoupler of the microchip laser 500.

[0039] The dichroic coating 540 is formed on a surface of the microchip laser base 510 opposite from the interfacial coating 530. In an embodiment, the dichroic coating 540 exhibits approximately 100% transmittance of light at a wavelength of 940nm, and approximately 100% reflectance of light at a wavelength of 1030nm.

[0040] The thickness of the microchip laser 500 is selected such that the microchip laser 500 limits the total spectral output to three longitudinal modes. In an embodiment, the overall thickness of the microchip laser 500 is approximately 2.02mm. The microchip laser 500 emits only one longitudinal mode per pulse over a relatively large range of temperature and pump diode currents.

[0041] Although FIGURE 5 illustrates one example of the microchip laser 500, various changes may be made to FIGURE 5. For example, it is possible to dope the solid etalon 520 with an inert ion. In addition, although the base regions 512, 514 are doped with Yb and Cr respectively, the base regions may be doped with other ions or be formed of other materials.

[0042] FIGURES 6A and 6B illustrate etalon and cavity mode graphs of the microchip laser 500, according to an embodiment of this disclosure. Similar to the graphs shown in FIGURES 3A and 3B, each of the graphs in FIGURES 6A and 6B includes an etalon plot line 605 and a cavity mode plot line 610. The etalon plot line 605 shows the change in the reflectivity of the etalon over different wavelengths. The cavity mode plot line 610 depicts the cavity modes of the overall microchip cavity over different wavelengths. The plot lines in FIGURE 6B represent the same information as the plot lines in FIGURE 6A, however the scale of the X-axis in FIGURE 6B is compressed and more than one cycle of each curve is shown. As shown in FIGURE 6B, the period of the etalon plot line 605 is approximately 1.3nm. It can be seen that the etalon plot line 605 and the cavity mode plot line 610 track each other over a number of periods.

Claims

1. A microchip laser (200; 500), comprising:
a microchip laser base (210; 510) comprising a

gain region (212; 512) and a passive Q-switch region (214; 514);
 a solid etalon (220; 520) coupled to the microchip laser base (210; 510); and
 an interfacial coating (230; 530) disposed between the microchip laser base (210; 510) and the solid etalon (220; 520);
 wherein the microchip laser base (210; 510) and the solid etalon (220; 520) are comprised of a same host material;
 wherein the microchip laser base (210; 510), the solid etalon, and the interfacial coating are bonded together without an adhesive;
 wherein the microchip laser base (210; 510) and the solid etalon (220; 520) form a laser cavity, thicknesses of the microchip laser base (210; 510) and the solid etalon (220; 520) being selected such that an emitted longitudinal mode of the laser cavity is at or near a peak reflectance of the solid etalon (220; 520); and
 wherein either:

an emitting outer surface (222; 522) of the solid etalon is an uncoated outer surface, and the interfacial coating (230; 530) has a reflectance that matches a Fresnel reflectance of the emitting outer surface (222; 522) of the solid etalon (220; 520); or
 the emitting outer surface (222; 522) of the solid etalon (220; 520) has a surface coating, and the reflectance of the interfacial coating (230; 530) matches a reflectance of the emitting outer surface (222; 522) of the solid etalon (220; 520).

2. The microchip laser (200; 500) of Claim 1, further comprising a dichroic coating (240; 540) disposed on a surface of the microchip laser base (210; 510) opposite the interfacial coating (230; 530).
3. The microchip laser (500) of Claim 1, wherein an overall thickness of the microchip laser (500) is selected such that the microchip laser (500) is configured to lase at three different longitudinal modes.
4. The microchip laser (200; 500) of Claim 1, wherein the microchip laser (200; 500) lases on only one longitudinal mode.
5. The microchip laser (200; 500) of Claim 1, wherein the microchip laser (200; 500) lases on only one longitudinal mode per pulse.
6. A laser system (100), comprising:

a pump diode (104) configured to produce light at a first wavelength;
 relay optics (120) configured to receive the light

from the pump diode (104); and
 a microchip laser (130) according to any preceding claim configured to receive the light from the relay optics (120).

7. A method of producing a laser output, the method comprising:

producing a light at a first wavelength;
 receiving, at a microchip laser (200; 500), the light at the first wavelength; and
 generating, at the microchip laser (200; 500), the laser output, the microchip laser (200; 500) comprising:

a microchip laser base (210; 510) comprising a gain region (212; 512) and a passive Q-switch region (214; 514);
 a solid etalon (220; 520) coupled to the microchip laser base (210; 510); and
 an interfacial coating (230; 530) disposed between the microchip laser base (210; 510) and the solid etalon (220; 520);
 wherein the microchip laser base (210; 510) and the solid etalon (220; 520) are comprised of a same host material;
 wherein the microchip laser base (210; 510), the solid etalon and the interfacial coating are bonded together without an adhesive;
 wherein the microchip laser base (210; 510) and the solid etalon (220; 520) form a laser cavity, thicknesses of the microchip laser base (210; 510) and the solid etalon (220; 520) being selected such that an emitted longitudinal mode of the laser cavity is at or near a peak reflectance of the solid etalon (220; 520); and
 wherein either:

an emitting outer surface (222; 522) of the solid etalon is an uncoated outer surface, and the interfacial coating (230; 530) has a reflectance that matches a Fresnel reflectance of the emitting outer surface (222; 522) of the solid etalon (220; 520); or
 the emitting outer surface (222; 522) of the solid etalon (220; 520) has a surface coating, and the reflectance of the interfacial coating (230; 530) matches a reflectance of the emitting outer surface (222; 522) of the solid etalon (220; 520).

8. The method of Claim 7, the microchip laser (200; 500) further comprising a dichroic coating (240; 540) disposed on a surface of the microchip laser base (210; 510) opposite the interfacial coating (230; 530).

9. The method of Claim 7, wherein an overall thickness of the microchip laser (500) is selected such that the microchip laser (500) is configured to lase at three different longitudinal modes.
10. The method of claim 7, wherein the microchip laser (200; 500) lases on only one longitudinal mode.
11. The method of Claim 7, wherein the microchip laser (200; 500) lases on only one longitudinal mode per pulse.

Patentansprüche

1. Mikrochip-Laser (200; 500), umfassend:

eine Mikrochip-Laserbasis (210; 510), die eine Verstärkungsregion (212; 512) und eine passive Güteschalterregion (214; 514) umfasst; ein festes Etalon (220; 520), das mit der Mikrochip-Laserbasis (210; 510) gekoppelt ist; und eine Grenzflächenbeschichtung (230; 530), die zwischen der Mikrochip-Laserbasis (210; 510) und dem festen Etalon (220; 520) angeordnet ist;

wobei die Mikrochip-Laserbasis (210; 510) und das feste Etalon (220; 520) aus dem gleichen Wirtsmaterial bestehen;

wobei die Mikrochip-Laserbasis (210; 510), das feste Etalon und die Grenzflächenbeschichtung ohne ein Haftmittel aneinandergebunden sind; wobei die Mikrochip-Laserbasis (210; 510) und das feste Etalon (220; 520) einen Laserhohlraum bilden, wobei Dicken der Mikrochip-Laserbasis (210; 510) und des festen Etalons (220; 520) so ausgewählt sind, dass ein Emissions-Längsmodus des Laserhohlraums bei oder fast bei einem höchsten Reflexionsgrad des festen Etalons (220; 520) liegt; und wobei entweder:

eine emittierende Außenfläche (222; 522) des festen Etalons eine unbeschichtete Außenfläche ist und die Grenzflächenbeschichtung (230; 530) einen Reflexionsgrad aufweist, der einem Fresnel-Reflexionsgrad der emittierenden Außenfläche (222; 522) des festen Etalons (220; 520) gleichkommt; oder

die emittierende Außenfläche (222; 522) des festen Etalons (220; 520) eine Oberflächenbeschichtung aufweist und der Reflexionsgrad der Grenzflächenbeschichtung (230; 530) einem Reflexionsgrad der emittierenden Außenfläche (222; 522) des festen Etalons (220; 520) gleichkommt.

2. Mikrochip-Laser (200; 500) nach Anspruch 1, ferner eine dichroitische Beschichtung (240; 540) umfassend, die auf einer Oberfläche der Mikrochip-Laserbasis (210; 510) entgegengesetzt zur Grenzflächenbeschichtung (230; 530) angeordnet ist.

3. Mikrochip-Laser (500) nach Anspruch 1, wobei eine Gesamtdicke des Mikrochip-Lasers (500) so ausgewählt ist, dass der Mikrochip-Laser (500) dafür ausgelegt ist, in drei unterschiedlichen Längsmodi zu lasern.

4. Mikrochip-Laser (200; 500) nach Anspruch 1, wobei der Mikrochip-Laser (200; 500) in nur einem Längsmodus lasert.

5. Mikrochip-Laser (200; 500) nach Anspruch 1, wobei der Mikrochip-Laser (200; 500) pro Impuls in nur einem Längsmodus lasert.

6. Lasersystem (100), umfassend:

eine Pumpdiode (104), die dafür ausgelegt ist, Licht mit einer ersten Wellenlänge zu produzieren;

eine Relaisoptik (120), die dafür ausgelegt ist, das Licht von der Pumpdiode (104) zu empfangen; und

einen Mikrochip-Laser (130) nach einem der vorangehenden Ansprüche, der dafür ausgelegt ist, das Licht von der Relaisoptik (120) zu empfangen.

7. Verfahren zum Produzieren einer Laserausgabe, wobei das Verfahren umfasst:

Produzieren von Licht mit einer ersten Wellenlänge;

Empfangen des Lichtes mit der ersten Wellenlänge an einem Mikrochip-Laser (200; 500); und Erzeugen der Laserausgabe am Mikrochip-Laser (200; 500), wobei der Mikrochip-Laser (200; 500) umfasst:

eine Mikrochip-Laserbasis (210; 510), die eine Verstärkungsregion (212; 512) und eine passive Güteschalterregion (214; 514) umfasst;

ein festes Etalon (220; 520), das mit der Mikrochip-Laserbasis (210; 510) gekoppelt ist; und

eine Grenzflächenbeschichtung (230; 530), die zwischen der Mikrochip-Laserbasis (210; 510) und dem festen Etalon (220; 520) angeordnet ist;

wobei die Mikrochip-Laserbasis (210; 510) und das feste Etalon (220; 520) aus dem gleichen Wirtsmaterial bestehen;

wobei die Mikrochip-Laserbasis (210; 510), das feste Etalon und die Grenzflächenbeschichtung ohne ein Haftmittel aneinandergebunden sind;

wobei die Mikrochip-Laserbasis (210; 510) und das feste Etalon (220; 520) einen Laserhohlraum bilden, wobei Dicken der Mikrochip-Laserbasis (210; 510) und des festen Etalons (220; 520) so ausgewählt sind, dass ein Emissions-Längsmodus des Laserhohlraums bei oder fast bei einem höchsten Reflexionsgrad des festen Etalons (220; 520) liegt; und
wobei entweder:

eine emittierende Außenfläche (222; 522) des festen Etalons eine unbeschichtete Außenfläche ist und die Grenzflächenbeschichtung (230; 530) einen Reflexionsgrad aufweist, der einem Fresnel-Reflexionsgrad der emittierenden Außenfläche (222; 522) des festen Etalons (220; 520) gleichkommt; oder
die emittierende Außenfläche (222; 522) des festen Etalons (220; 520) eine Oberflächenbeschichtung aufweist und der Reflexionsgrad der Grenzflächenbeschichtung (230; 530) einem Reflexionsgrad der emittierenden Außenfläche (222; 522) des festen Etalons (220; 520) gleichkommt.

8. Verfahren nach Anspruch 7, wobei der Mikrochip-Laser (200; 500) ferner eine dichroitische Beschichtung (240; 540) umfasst, die auf einer Oberfläche der Mikrochip-Laserbasis (210; 510) entgegengesetzt zur Grenzflächenbeschichtung (230; 530) angeordnet ist.

9. Verfahren nach Anspruch 7, wobei eine Gesamtdicke des Mikrochip-Lasers (500) so ausgewählt wird, dass der Mikrochip-Laser (500) dafür ausgelegt ist, in drei unterschiedlichen Längsmodi zu lasern.

10. Verfahren nach Anspruch 7, wobei der Mikrochip-Laser (200; 500) in nur einem Längsmodus lasert.

11. Verfahren nach Anspruch 7, wobei der Mikrochip-Laser (200; 500) pro Impuls in nur einem Längsmodus lasert.

Revendications

1. Laser à micropuce (200 ; 500) comprenant :

une base laser à micropuce (210 ; 510) compor-

tant une région de gain (212 ; 512) et une région passive à fonctionnement déclenché (214 ; 514) ;

un étalon solide (220 ; 520) couplé à la base laser à micropuce (210 ; 510) ; et

un revêtement interfacial (230 ; 530) disposé entre la base laser à micropuce (210 ; 510) et l'étalon solide (220 ; 520) ;

la base laser à micropuce (210 ; 510) et l'étalon solide (220 ; 520) étant constitués d'un même matériau hôte ;

la base laser à micropuce (210 ; 510), l'étalon solide et le revêtement interfacial étant liés ensemble sans adhésif ;

la base laser à micropuce (210 ; 510) et l'étalon solide (220 ; 520) formant une cavité laser, l'épaisseur de la base laser à micropuce (210 ; 510) et l'épaisseur de l'étalon solide (220 ; 520) étant sélectionnées de telle sorte qu'un mode longitudinal émis de la cavité laser soit à une réflectance maximale, ou proche de celle-ci, de l'étalon solide (220 ; 520) ; et

ou bien

une surface extérieure émettrice (222 ; 522) de l'étalon solide étant une surface externe non revêtue, et le revêtement interfacial (230 ; 530) ayant une réflectance qui correspond à une réflectance de Fresnel de la surface extérieure émettrice (222 ; 522) de l'étalon solide (220 ; 520) ; ou bien

la surface extérieure émettrice (222, 522) de l'étalon solide (220 ; 520) ayant un revêtement de surface et la réflectance du revêtement interfacial (230 ; 530) correspondant à la réflectance de la surface extérieure émettrice (222 ; 522) de l'étalon solide (220 ; 520).

2. Laser à micropuce (200 ; 500) selon la revendication 1, comprenant en outre un revêtement dichroïque (240 ; 540) disposé sur une surface de la base laser à micropuce (210 ; 510) opposée au revêtement interfacial (230 ; 530).

3. Laser à micropuce (500) selon la revendication 1, l'épaisseur globale du laser à micropuce (500) étant sélectionnée de telle sorte que le laser à micropuce (500) est conçu pour émettre des faisceaux laser dans trois modes longitudinaux différents.

4. Laser à micropuce (200 ; 500) selon la revendication 1, le laser à micropuce (200 ; 500) n'émettant des faisceaux laser que dans un seul mode longitudinal.

5. Laser à micropuce (200 ; 500) selon la revendication 1, le laser à micropuce (200 ; 500) n'émettant des faisceaux laser que dans un seul mode longitudinal par impulsion.

6. Système laser (100) comprenant :

une diode de pompage (104) conçue pour produire de la lumière à une première longueur d'onde ;
un relais optique (120) conçu pour recevoir la lumière de la diode de pompage (104) ; et
un laser à micropuce (130) selon l'une quelconque des revendications précédentes conçu pour recevoir la lumière du relais optique (120).

7. Procédé de production d'un signal de sortie laser, le procédé comprenant :

la production d'une lumière à une première longueur d'onde ;
la réception, au niveau d'un laser à micropuce (200 ; 500), de la lumière à la première longueur d'onde ; et
la génération, au niveau du laser à micropuce (200 ; 500), du signal de sortie laser, le laser à micropuce (200 ; 500) comprenant :

une base laser à micropuce (210 ; 510) comprenant une région de gain (212 ; 512) et une région passive à fonctionnement déclenché (214 ; 514) ;
un étalon solide (220 ; 520) couplé à la base laser à micropuce (210 ; 510) ; et
un revêtement interfacial (230 ; 530) disposé entre la base laser à micropuce (210 ; 510) et l'étalon solide (220 ; 520) ;
la base laser à micropuce (210 ; 510) et l'étalon solide (220 ; 520) étant constitués d'un même matériau hôte ;
la base laser à micropuce (210 ; 510), l'étalon solide et le revêtement interfacial étant liés ensemble sans adhésif ;
la base laser à micropuce (210 ; 510) et l'étalon solide (220 ; 520) formant une cavité laser, l'épaisseur de la base laser à micropuce (210 ; 510) et l'épaisseur de l'étalon solide (220 ; 520) étant sélectionnées de telle sorte que le mode longitudinal émis de la cavité laser est à une réflectance maximale, ou proche de celle-ci, de l'étalon solide (220 ; 520) ; et
ou bien :

une surface extérieure émettrice (222 ; 522) de l'étalon solide étant une surface extérieure non revêtue, et le revêtement interfacial (230 ; 530) ayant une réflectance qui correspond à une réflectance de Fresnel de la surface extérieure émettrice (222 ; 522) de l'étalon solide (220 ; 520) ; ou bien
la surface extérieure émettrice (222,

522) de l'étalon solide (220 ; 520) ayant un revêtement de surface, et la réflectance du revêtement interfacial (230 ; 530) correspondant à une réflectance de la surface extérieure émettrice (222 ; 522) de l'étalon solide (220 ; 520).

8. Procédé selon la revendication 7, le laser à micropuce (200 ; 500) comprenant en outre un revêtement dichroïque (240 ; 540) disposé sur une surface de la base laser à micropuce (210 ; 510) opposée au revêtement interfacial (230 ; 530).

9. Procédé selon la revendication 7, dans lequel épaisseur globale du laser à micropuce (500) sélectionnée de telle sorte que le laser à micropuce (500) soit configuré pour émettre des faisceaux laser dans trois modes longitudinaux différents.

10. Procédé selon la revendication 7, dans lequel le laser à micropuce (200 ; 500) n'émet des faisceaux laser que dans un mode longitudinal.

11. Procédé selon la revendication 7, dans lequel le laser à micropuce (200 ; 500) n'émet des faisceaux laser que dans un mode longitudinal par impulsion.

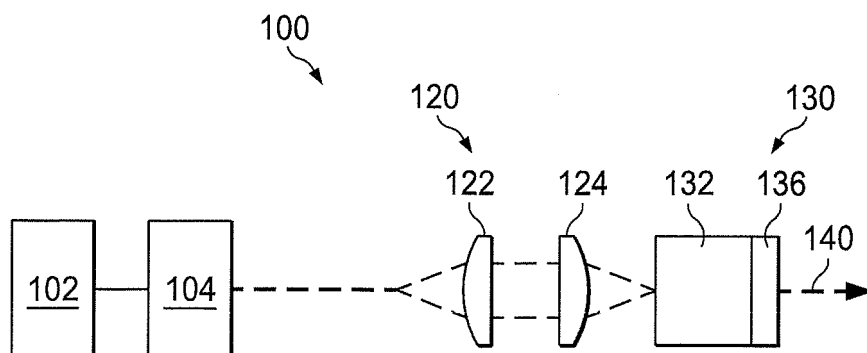


FIG. 1

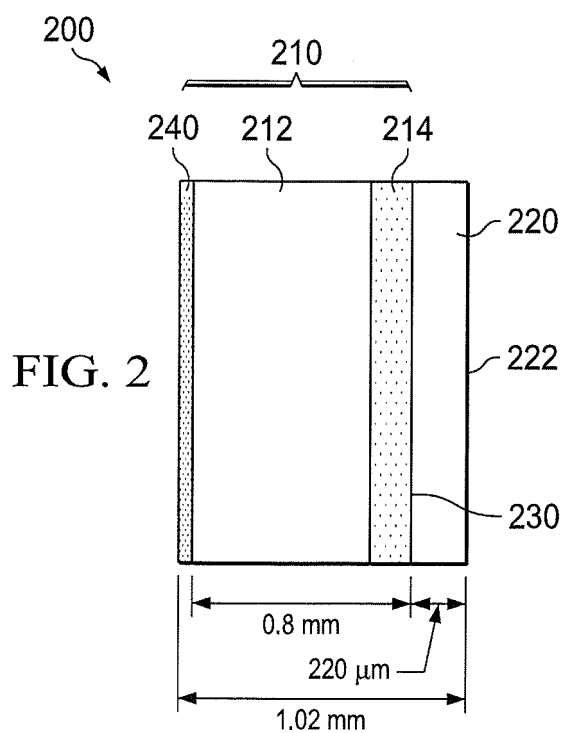


FIG. 2

FIG. 3A

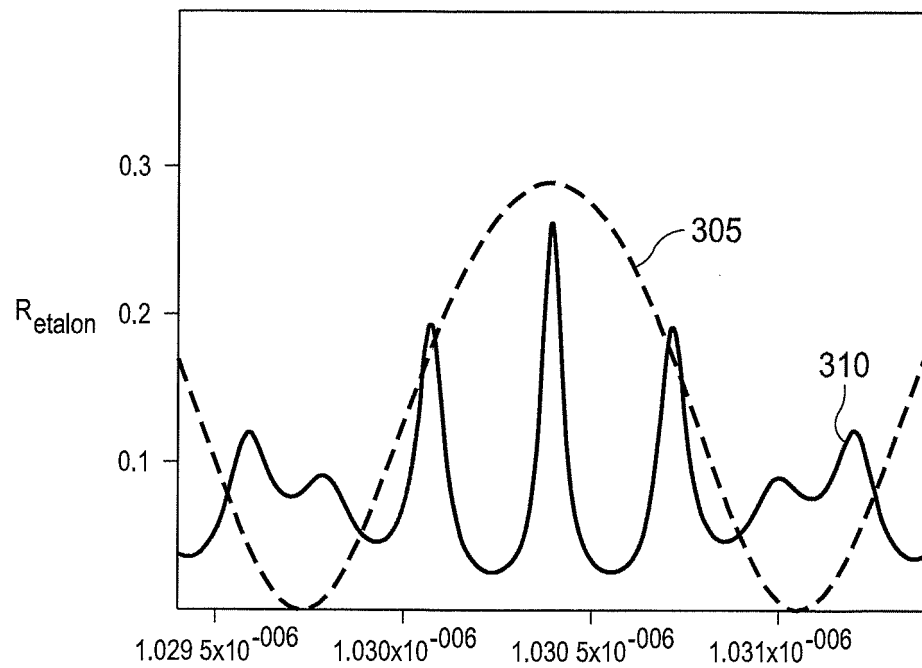


FIG. 3B

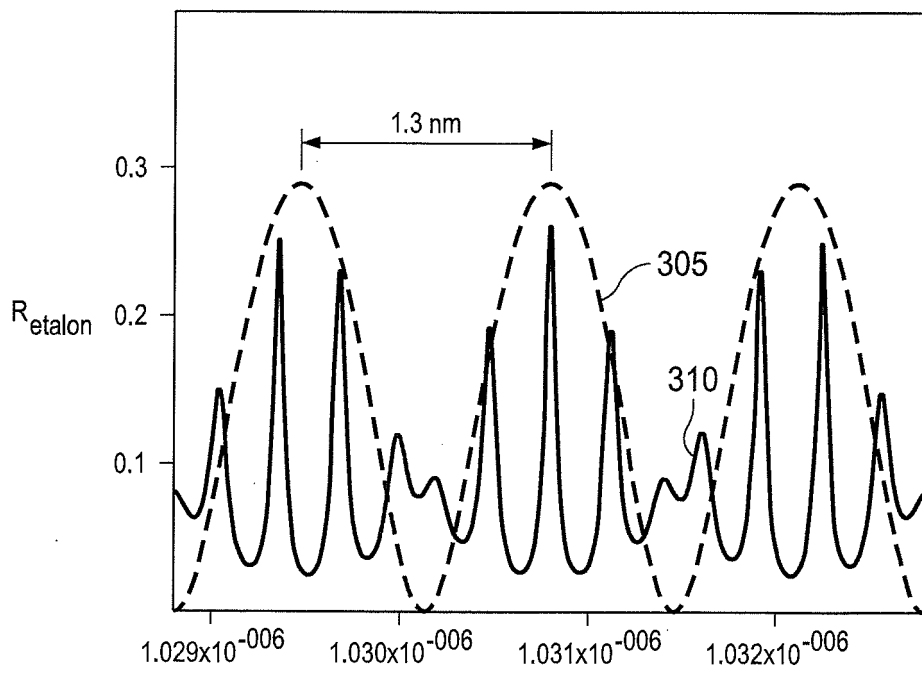


FIG. 4A

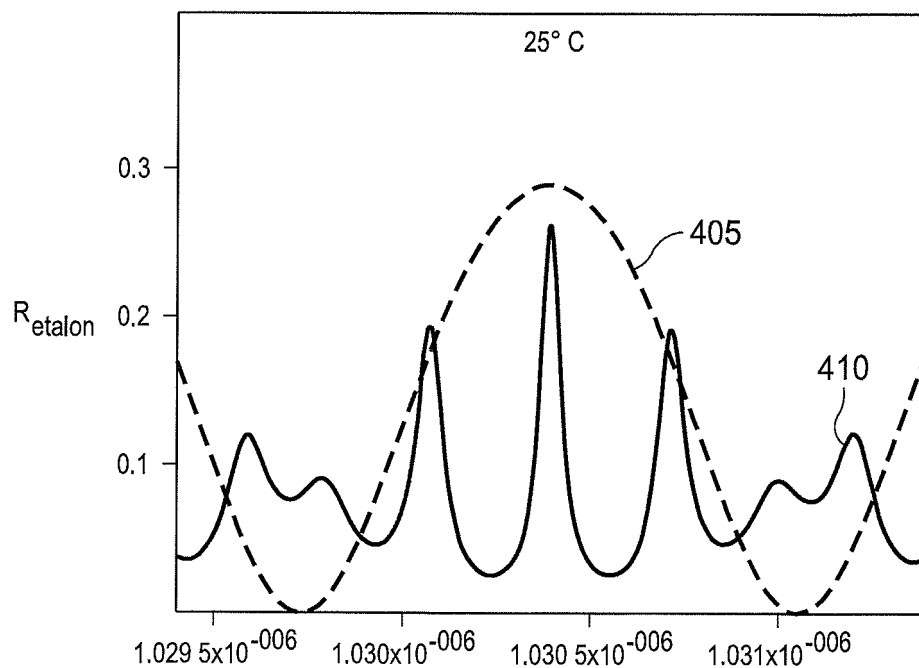


FIG. 4B

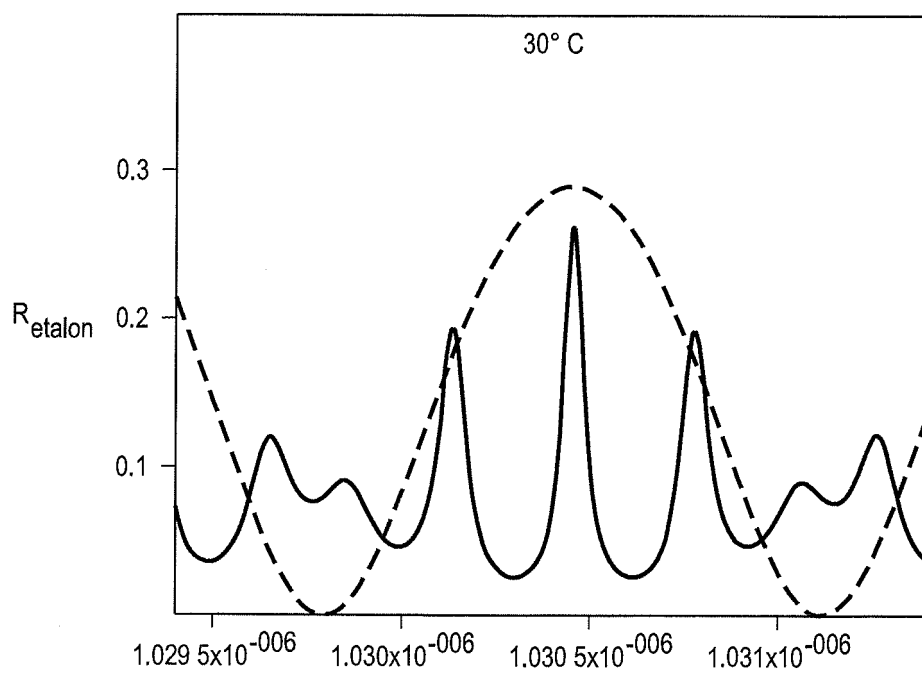


FIG. 4C

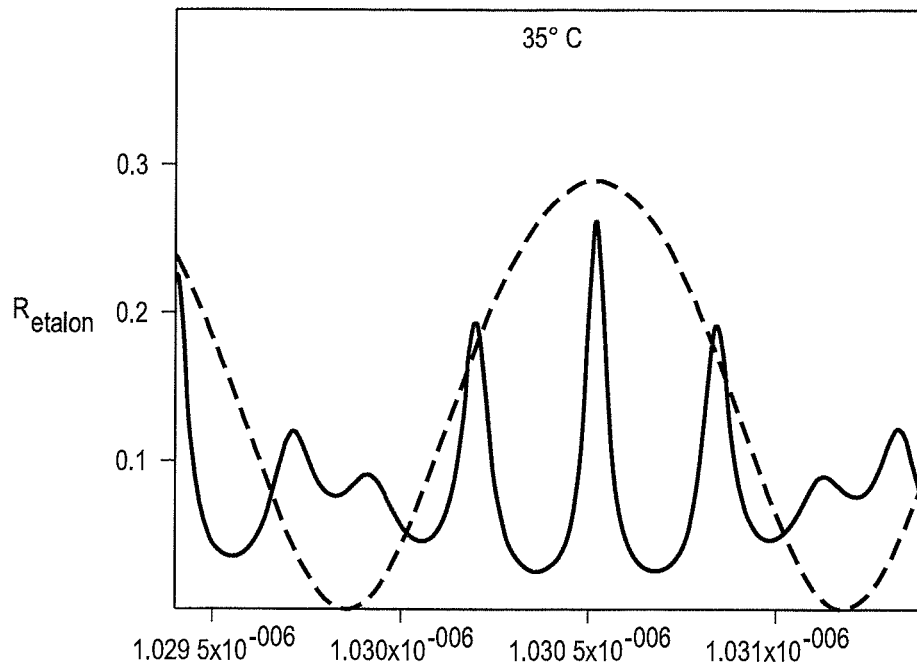


FIG. 4D

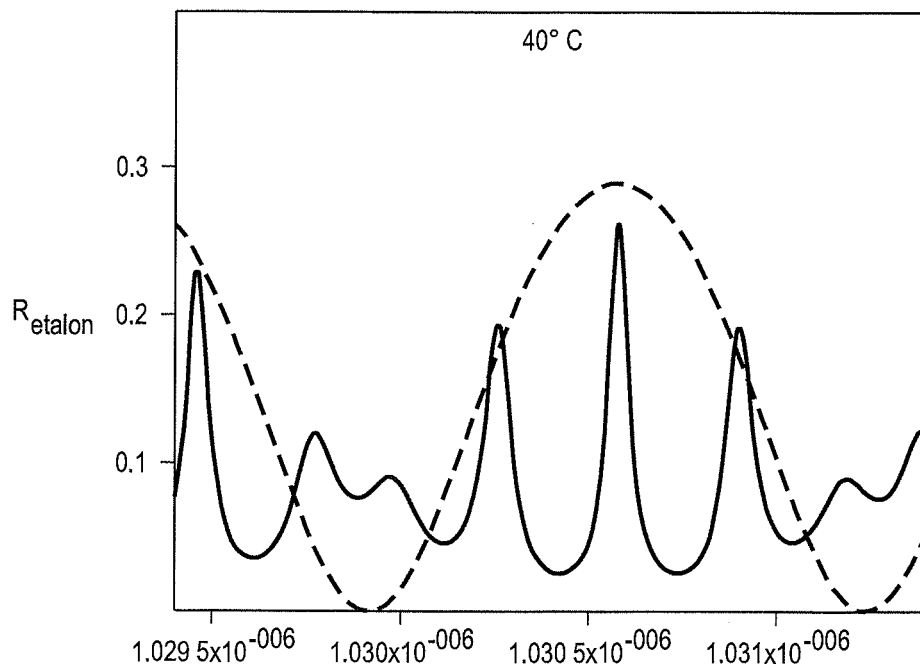


FIG. 4E

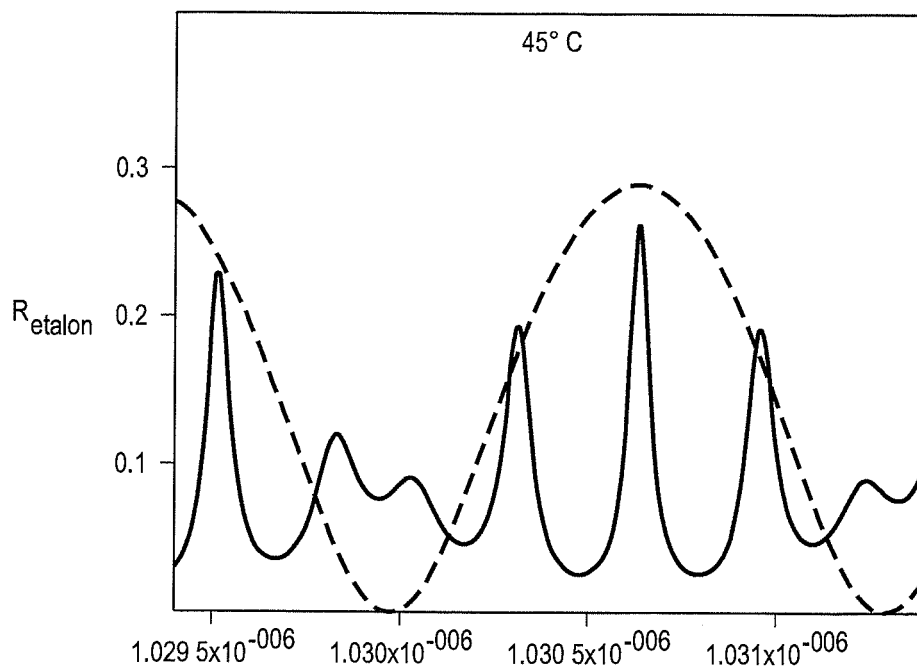
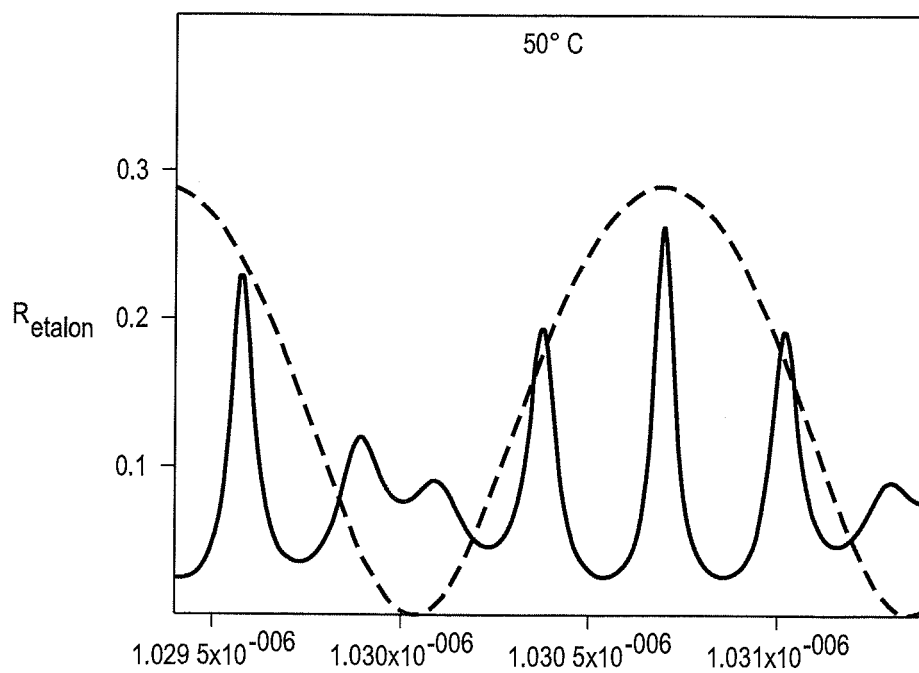


FIG. 4F



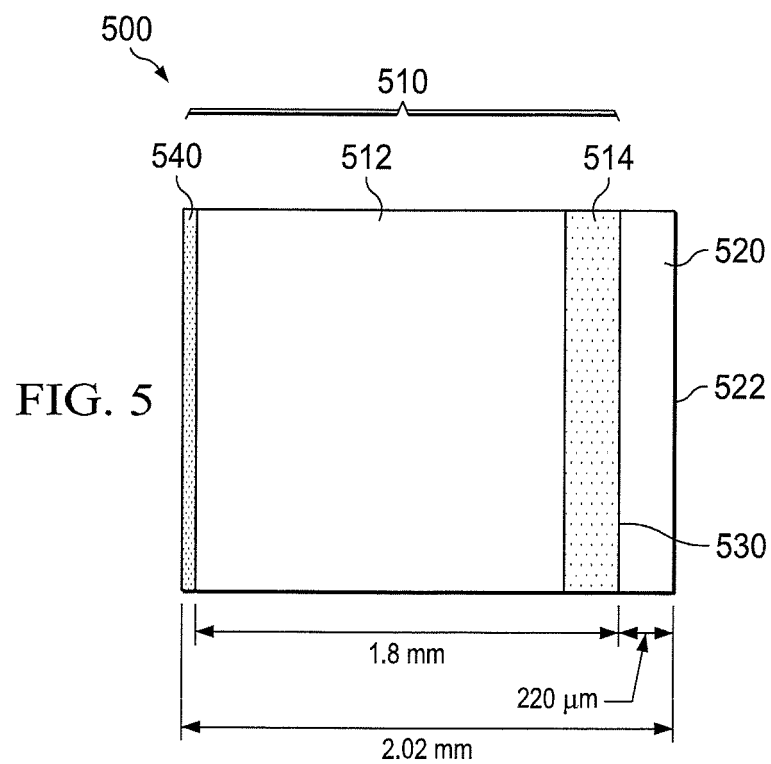


FIG. 6A

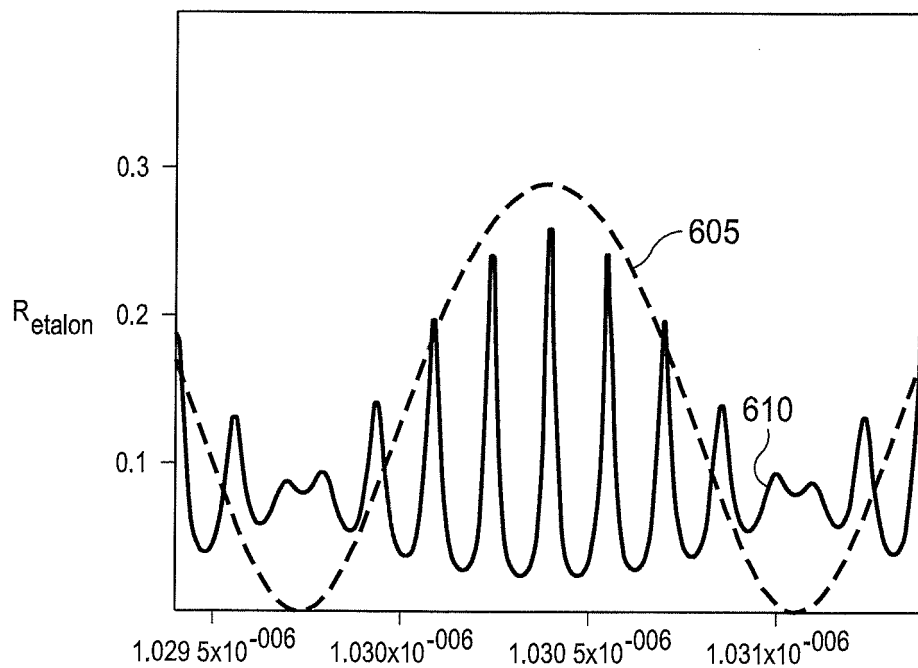
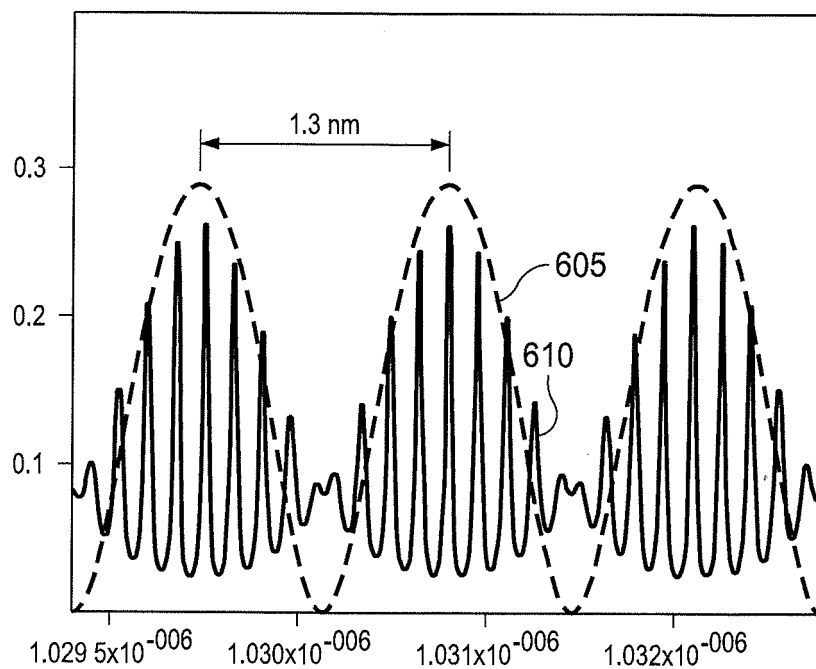


FIG. 6B



REFERENCES CITED IN THE DESCRIPTION

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